In situ, in vitro and in silico analysis of coating performance

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Abstract

Service life prediction (SLP) is a complex yet essential method for analysing coating performance. Accurate and precise assessment is crucial for a strong position on the market. Correct knowledge of the critical failure points, maintenance/replacement frequency and related costs are part of this approach. This paper describes the scale-dependent tools within a bio-engineering framework that are applied for coating research, ranging from modelling, X-ray tomography, lab testing, controlled fungal infestation up to continuous moisture set-ups and large-scale window frame weathering.

1. Introduction

Standard service life prediction (SLP) relies on the correlation between natural weathering and accelerated ageing and the adaption of parameters when correlation is insufficient. Basically, this amounts to the use of an accelerated device such as a UV cabinet or similar and comparing colour, gloss, water absorption and other parameters before and after several weathering cycles with the results of an outdoor set-up (Martin 1999). A next step in the development of a reliable SLP methodology is the incorporation of a dose accumulation / damage function in order to estimate the dose response of the material regarding its susceptibility towards weathering. As such it should be sufficient to measure the dose in artificial weathering to result in an estimate of its state of degradation once correlated with its outdoor equivalent. In order to work out such an SLP tool, one has to know the properties and failure modes of the coating systems. The current state-of-the-art regarding imaging modalities, chemical analysis tools and soft- and hardware offer the opportunity of advanced monitoring and computing and are a significant contribution to the field. Especially X-ray tomography and confocal laser microscopy are very valuable. Starting from literature data, measurements on-site and in the laboratory, theoretical calculations are within reach as well. This paper therefore elaborates on the tools that are available within the framework of a bio-engineering laboratory of wood technology, covering *in situ* (outdoor) set-ups, *in vitro* (laboratory) experiments and *in silico* (computer) simulations and calculations. Most of the work has been published in international journals or has been presented on international conferences. As such the interested reader is referred to these papers throughout this paper for more detailed information.

2. Scale-dependent tools

The scale-dependent research at the Lab of Wood Technology comprises a whole range of experimental set-ups aiming at increasing the knowledge of coatings ranging from the fundamental level up to monitoring of whole window frames. A top down approach will be followed.

In situ

Whole window framing

The idea of whole window testing is to incorporate daily processing of window frames, starting from the assembling of the window from the wood material up to spray-coating of the frame itself. As such, the industrial manufacturing as it is done normally is included in the experiment. This is of course an advantage compared to the use of simple boards in a laboratory approach, yet has the disadvantage of sampling, replicates and monitoring intensiveness. This expiremental set-up fits within the projects Assesswoodcoat and Optiwoodcoat, both dealing with coating assessment to result in a set of parameters describing the minimum requirements of a coated structure, in this case window frames (De Windt et al. 2008a, 2008b). The set-up at the Laboratory of Wood Technology is illustrated in Figure 1 and is situated in an urban area.

Fig. 1. Full window frame testing at the Laboratory of Wood Technology

A similar set of windows is realised in Bertrix and Ieper, representing respectively a more rural environment and a sea climate. As such three mesoclimatic situations are created for outdoor weathering. The condition of these frames is monitored by means of general visual assessment (cracks, fissures, etc), colour, gloss, mass change and fungal growth in form of mould, blue staining and, in extreme cases, even rot fungi are detected.

CMM approach

The continuous moisture measurement approach is already elaborated for plywood (Van den Bulcke and Van Acker 2008, Van Acker and De Smet 2007). It considers a continuous monitoring of the weight of samples, be it coated or not, mounted on load cells. Figure 2 outlines such a set-up for plywood.

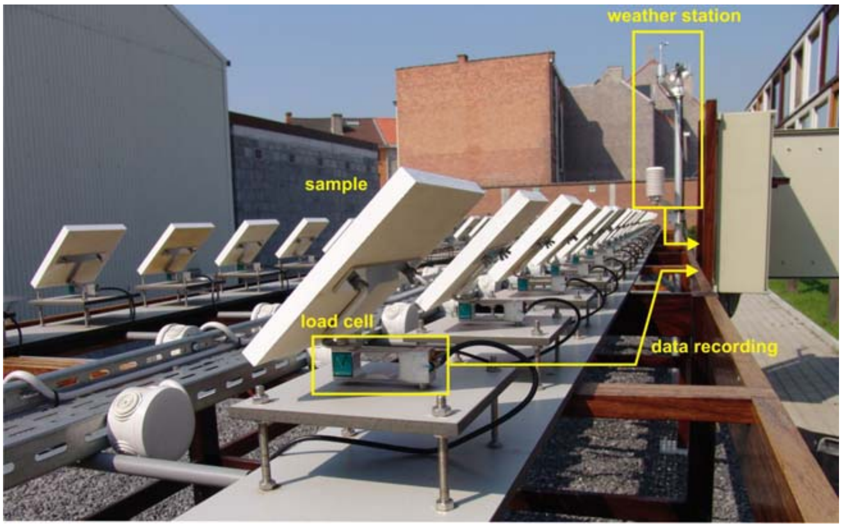


Fig. 2. CMM of plywood

In combination with a weather station, full climatic monitoring can be related to the behaviour of the samples, which can be realized by developing an engineering prediction tool based on recurrent neural nets. By specific incorporation of substrate characteristics, possibly, estimations of substrate behaviour are within reach. A same set-up is worked-out for coated wood in order to follow the moisture dynamics during weathering and pinpoint at the critical failure points such as moisture accumulation induced blistering or cracking.

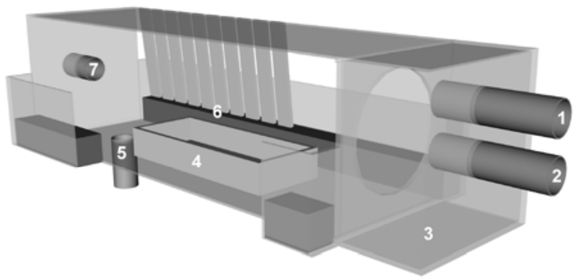
In vitro

Accelerated ageing

Apart from the outdoor weathering, for the Assesswoodcoat and Optiwoodcoat project, samples taken from replicate window frames were used in accelerated ageing tests. A whole range of parameters was monitored: colour, gloss, dimensional changes, layer thickness, penetration depth, fungal deterioration, moisture absorption, etc. By comparison with the outdoor measured parameters, acceleration factors can be calculated and minimum requirements can be determined for adequate in-service performance (De Windt et al. 2008a).

Fungal testing

Although coated wood is normally not subjected to severe degradation by rot fungi, disfigurement is often encountered. One can state that discoloration has to be regarded as a failure if aesthetics is strived for. Therefore, assessment of the blue staining and mould cover susceptibility of coatings is also part of the SLP research at the lab. In addition to the standard tests, a fungal control unit is applied, being a closed environment with controllable temperature and relative humidity (Figure 3), built by analogy with a standard UV cabinet.



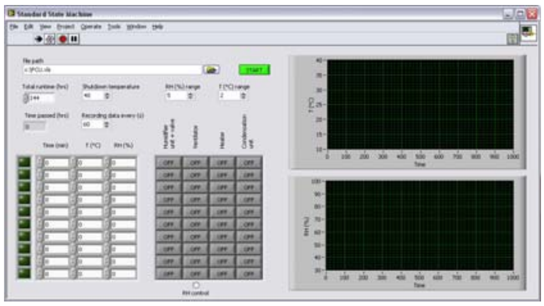


Fig. 3. Concept of the FCU (Fungal Control Unit)

Due to its flexible tuning, any cycle can be programmed in order to mimic outdoor conditions or approach optimal conditions for fungal development. As such the reaction of a coating weathered or not, regarding the deterioration by fungi, can be explored.

In silico

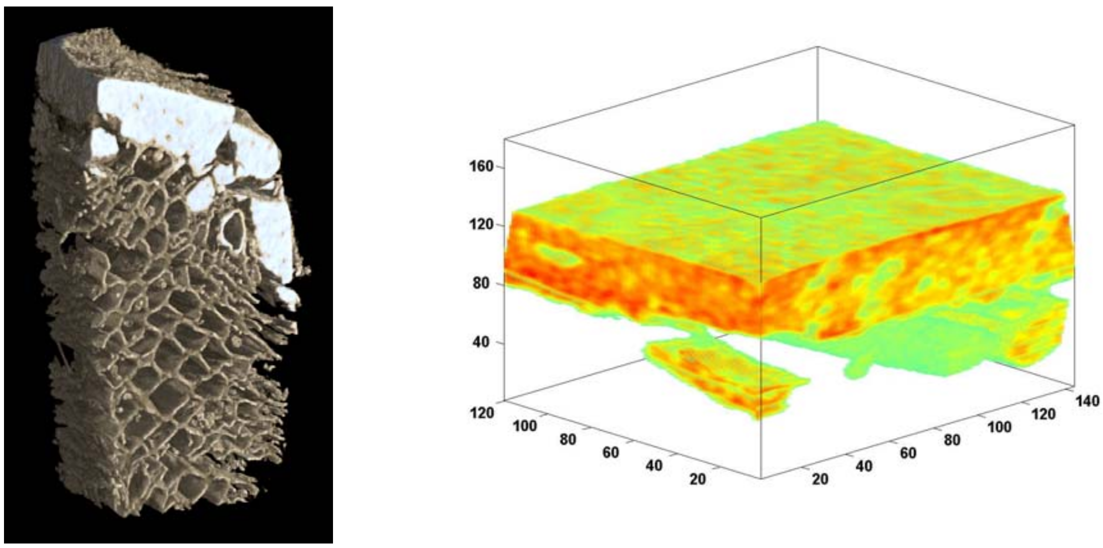
For quite some time now an important part of research efforts are focused on computer-assisted reliability based service life predictions in order to estimate a service / performance lifetime or otherwise, a probability of failure. For coating research this topic was touched upon by De Windt et al. (2008b), using the Weibull distribution of visual assessed window frames to predict failure of a partially right-censored data set. A same procedure could be applied to the dataset of Van den

Bulcke et al. (2008) when setting criteria of failure for different measured parameters. Furthermore, application of time series modelling using the cumulative degradation technique combined with a Monte Carlo approach (Chan and Meeker, 2008) might lead to interesting insights. Otherwise, clustering of parameters (colour, gloss, adhesion, penetration, etc) of weathered samples might lead to ranking of coatings throughout the testing and might be used as a measure of performance once in accordance with outdoor behaviour.

Considering the CMM approach, an interesting line of reasoning can be explored taking into consideration the phenomenon of moisture dynamics which are monitored closely. Although no true service life prediction, by implementing a neural network trained with measurements and loaded with environmental and substrate-specific data, an engineering framework could be worked out to judge moisture balance of a material.

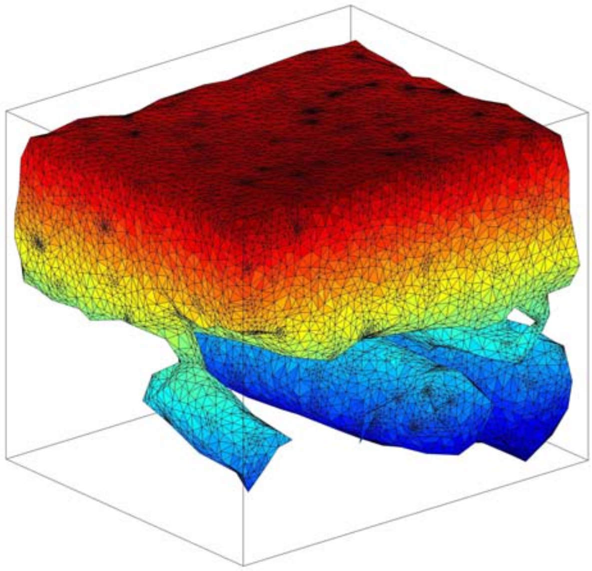
Further, measurements of different coating properties justify the effort of calculating parameters in order to predict them: penetration and adhesion are two of these parameters that are intensively studied by de Meijer (de Meijer, 1999) and a same, albeit slightly simplified procedure was elaborated in Van den Bulcke et al. (2008). The theoretical approach of coating application on wood could be further worked out by starting from the fluid coating as examined in Van den Bulcke et al. (2007). By using the Monte Carlo approach the drying of a coating and related surface roughness and gloss can be investigated and even, by implementation of weathering simulation (see also Croll and Hinderliter 2005), the influence of UV and rain can be evaluated *in silico*.

With high resolution but an appropriate field of view, the use of X-ray computed tomography offers a lot of opportunities in fundamental coating research with contribution towards service life prediction. In Figure 4a an example of such an X-ray scan is given, while in Figure 4b the segmented coating layer on the wood is depicted and in Figure 4c a volumetric mesh is generated for finite element analysis.



a b

Fig. 4. X-ray tomography of coated wood



c

Fig. 4. X-ray tomography of coated wood

Starting from X-ray CT-scans, a whole range of parameters can be derived from layer thickness, penetration depth up to coating porosity, surface roughness, etc. These can be compared to the calculations of coating penetration and surface roughness, but above this the segmented wood volume could be used for penetration simulation taking into account the measured characteristics of the coatings in order to result in a more reliable estimate. The FEM mesh of the coating as presented in Figure 4c further enables strength analysis of the coating for comparison with measured adhesion values.

3. Conclusions

The assembly of the tools listed above, enables a profound research regarding service life prediction of coatings. A combination of *in situ*, *in vitro* and *in silico* testing hopefully can support the coating manufacturer in an accurate assessment of new products.

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